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Original Research Article

Monitoring and predicting the soil water content in the deeper soil profile of Loess Plateau, China

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A B S T R A C T

Estimation of soil water content (SWC) in deep soil profiles is of crucial importance for strategic management of water resource for sustainable land use in arid and semi-arid zones, as well as for soil and water conservation. Soil properties have a very important effect on SWC. This study aimed to analyze the influence of soil particle size on SWC, for the first time using soil particle size to estimate SWC in deep soil profiles. SWC was measured mainly in farmland, natural grasslands and plantations of Caragana from the surface to more than 20 m depth. The same soil samples were also tested for particle size. The results show that the soil desiccation is formed in the caragana forest in 3–18 m soil layers, but almost no formation in 18–24 m layers; water content of farmland and grassland is different in all soil profiles although they are both shallow rooted plants. Correlation analysis indicated that SWC could be well predicted by clay content and the close correlation between SWC and clay content yielded a coefficient of determination (R^2) of 0.82 and 0.72, respectively, for farmland and grassland. After multiple regression analysis, a regression model was built using SWC, clay content and sand content data, giving $R^2=0.66$. The model provided reliable estimates of SWC profile based on textural class. This can assist in estimating water depletion by vegetation, by comparing moisture of farmland and grassland soils with that of plantation forests, and in selecting sustainable land use of arid land.

Contents

1. Introduction

Soil water content (SWC) is used to calculate "the available water storage capacity, which is defined as the moisture held between field capacity (FC) and permanent wilting point (PWP)" and is

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critical for practical application which is related to agricultural, water and soil resources management (Rao, 1998; Starks, Heathman, Ahujab, & Ma, 2003). It is also a critical factor in evaluating the suitability of the given vegetation in that region. The transmissivity parameters (e.g., soil hydraulic conductivity vs. SWC relationships) used in physically-based models that make basic assumptions of soil uniformity and homogeneity, are also highly sensitive to SWC (Givia, Prasher, & Patel, 2004). However, direct measurement of SWC is usually hard, expensive and time-consuming for most researches and management applications, especially on a relatively large scale. When the researched area is relatively homogeneous in its physical soil makeup and topography, SWC is related to other physical characteristics such as particle size distribution, structure, bulk density and organic matter content (Rao, 1998). It is possible to develop empirical relationships that provide adequate estimates of SWC through numbers of sampling sites which are inexpensive and easy to access. Most methods are named pedotransfer functions (PTFs) (Bouma & Van Lanen, 1987).

Correlations between soil properties (SWC, organic carbon content, and percentage of sand, silt, clay etc.) have been studied since early in the twentieth century (Briggs & Shantz, 1912; Salter & Williams, 1965; Doorenbos & Pruitt, 1977). With the development of computer modeling and databases, more PTFs have been developed (Rawls, Gish, & Brakensiek, 1991; Wösten, Pachepsky, & Rawls, 2001). Rawls, Brakensiek, and Saxton (1982) developed PTFs using 5350 sets of soil data. Baumer (1992) developed PTFs using 18 000 soil horizon measurements from the US National Soil Pedon Characterization database to predict SWCs at FC and wilting point (WP). Wösten, Lilly, Nemes, and Le Bas (1999) proposed PTFs based on the HYPRES database that contains 5521 sets of soil data. Bruand, Perez Fernandez, and Duval (2003) formulated PTFs use particle size and bulk density to calculate gravimetric water content at 7 water potentials. Furthermore, the accuracy of PTFs in predicting the SWC has been evaluated. Givia et al. (2004) showed that the PTFs developed for soils having similar characteristics to those being studied generally perform better than others. Cornelis, Ronsyn, Van Meirvenne, and Hartmann (2001) presented that a PTF performs much better if it is used to the developed region.

However, concrete measurement of the required soil characteristics is not practicable and the present PTFs are most be developed for estimating water retention and available water content in surface soil (Schaap, Nemes, & Van Genuchten, 2004). Currently, we can only get a crude spatial distribution of soil textural composition by field survey (Starks et al., 2003). Particle-size composition could be related to FC, WP, and available water content via regression equation (Pidgeon, 2006). The relationships predicting SWC have been developed from those found in different countries, including England (Pidgeon, 2006), USA (Leij, Alves, van Genuchten, & Williams, 1996), France (Bruand et al., 2003), Rosetta (Schaap, Leij, & Van Genuchten, 2001) and other parts of Europe (Wösten et al., 1999). In China there is still little data available.

Soil desiccation (SD) is a particular hydrological phenomenon in semiarid area of the Loess Plateau in China, which is induced by the excessive depletion of deep soil water and long-term insufficient rainfall supply (Chen, Shao, & Li, 2008). It was found firstly by Li (1983) in 1960s in semiarid area of Shaanxi and Gansu provinces and often took place below the depth of soil which was affected by rainfall infiltration about 3 m (Yang & Shao, 2000; Fan, Shao, & Wang, 2006; Li et al., 2007). However, it was paid limited attention to until 1980s, when it was found in artificial forestland with a depth from 0.4 m to more than 10 m (Yang & Yu, 1992; Mu, Xu, Wang, Wen, & Du, 2003, Wang, Shao, Wang, & Jia, 2005). In the present study we investigated the SWC of farmland, grassland and artificial vegetation. One specific objective of the study was first measurement of the SWC after rainy season of the soil and parent material from the surface to 24 m depth. And then discussion of the variations recorded due to the vegetation excessive depletion of deep soil water, evaluate the relationship between SWC and soil particle size and to develop a statistically supported PTF for predicting SWC from soil particle size data. The PTF should help us in sustainable land-use planning and soil and water conservation planning.

2. Materials and methods

2.1. Study area description

The study was carried out in the catchment of the Suide County Shaanxi Province, the semiarid area of the Loess Plateau of China (Fig. 1). The latitude is N37° 31′ 16″ with longitude is E110° 17′ 05″. Suide County occupies an area of approximately 1878 km^2. The climate is semi-arid with a yearly-averaged temperature of 9.7 °C, a yearly-averaged precipitation of 439 mm of which more than 70% falls from May to Sep. called wet season (Table 1). SWC was recharged in the wet season. The average annual potential evaporation is nearly 1900 mm. The landform is typical loess hilly landscape with an elevation ranging from 608 m to 1287 m. The soil is calcareous silt loam (Calcic Cambisols) with the parent material is loess. The field capacity is 15.8%, and the permanent wilting point is 4%. The present natural forest species are *Pyrus betulaefolia*, *Zizyphus sativa*, *Artemisia gmelini*, *A. grandii*, *Stipa bungeana*, *Heteropappus altaicus* and *Lespediza dahurica*. The regrown forest species are *Robinia pseudoacacia L*, *Pinus tabulaeformis*, *Platycladus orientalis*, *Ulmus pumila* and *Caragana microphylla Lam*. They were planted in late 1970s. Introduced turf is *Alfalfa*.

2.2. Sampling site

The sampling sites were within a limited area with similar topographic characteristics and altitude. The land use of three sites was farmland, grassland and caragana located on middle slope positions on east-facing slopes. The farmland crops are mainly annual crops (millet) and cash crops (castor oil plant, *Ricinus communis*). The castor oil plant was planted in 2007. The grassland

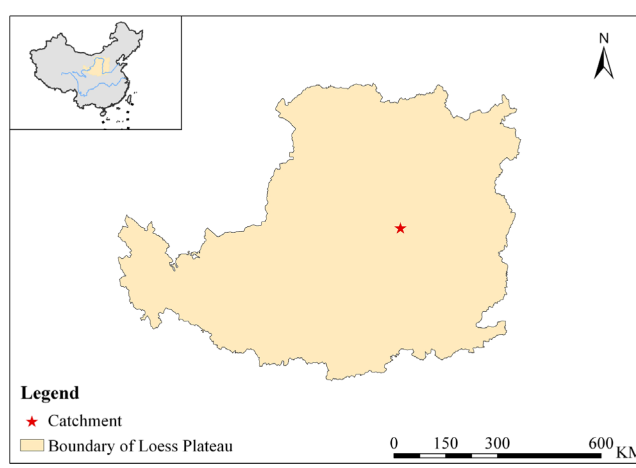

Fig. 1. The location of study catchment.

Table 1
Precipitation (mm) of Suide County, Shaanxi (1981–2010).

Annual	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
243	0	0	3	7	16	33	61	63	44	12	4	0